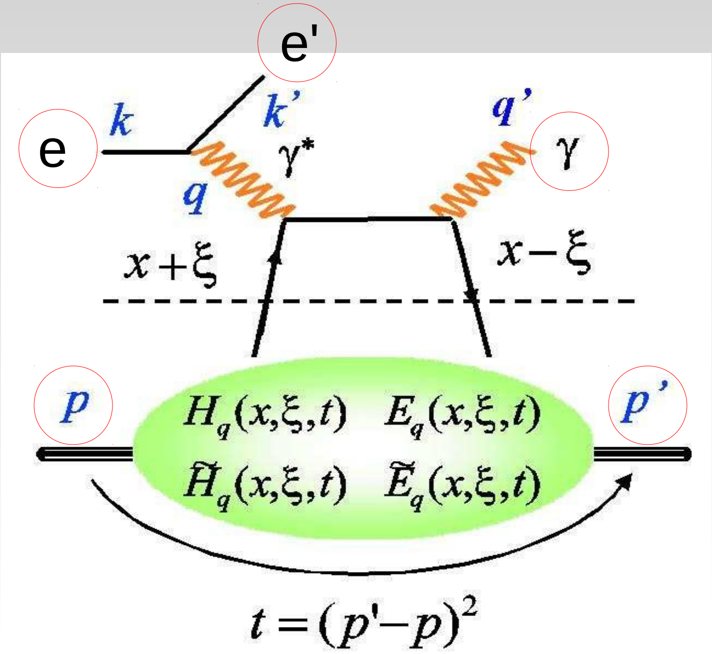
E08-025 DVCS Experiment in the Hall A :
Calibration monitoring of the calorimeter using π^0 events

IPNOrsay (France)

Camille Desnault

Presentation of the DVCS Experiment



DVCS : ep → e'pγ

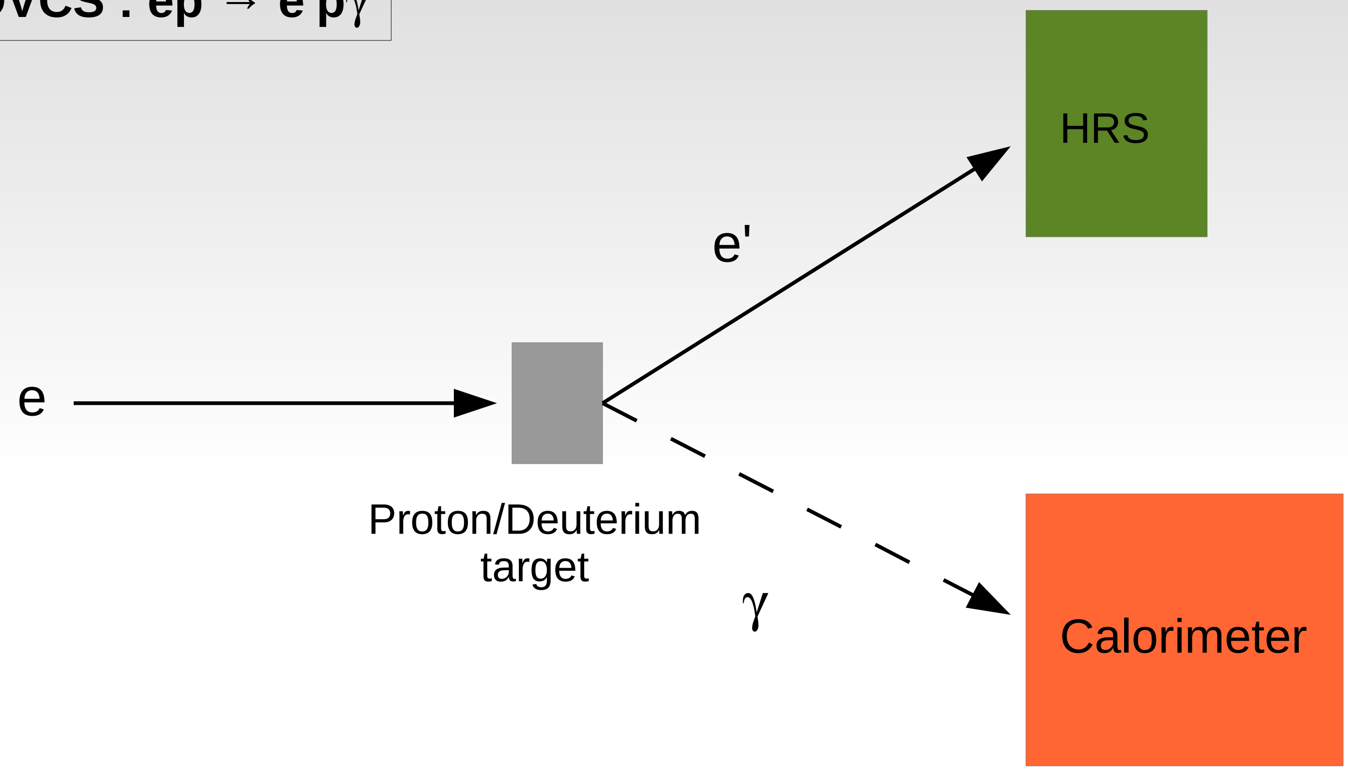
Deeply Virtual Compton Scattering (DVCS) is the simplest process which gives access at **Generalized Partons Distributions** (GPDs)

GPDs inform on the correlation between the **longitudinal momentum** and the **transverse position** of the quarks in the nucleon

- **<u>E08-025 DVCS Experiment</u>** :
  - Data taking in 2010 during 3 months
  - 2 Targets : LH2 and LD2
  - Measure of cross-section DVCS at :
    - 2 Beam Energies : 4.82 GeV and 6.0 GeV
    - Fixed $Q^2 = - q^2 = - (e-e')^2 = 1.9\ GeV^2$

Experimental set-up for the DVCS in the Hall A

DVCS : ep → e'pγ

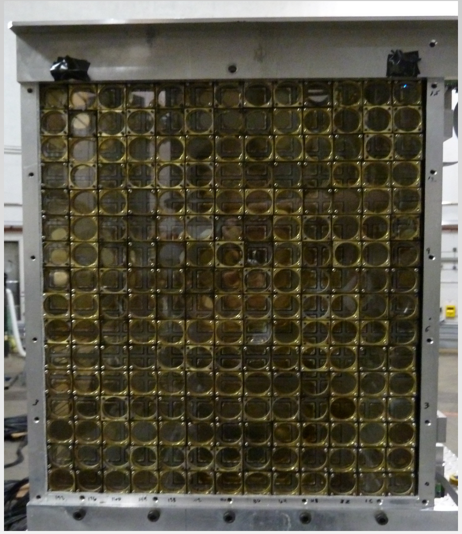


High resolution in Energy
→ Trigger on a good event

The <u>position</u> resolution of the calorimeter is <u>better</u> than its <u>energy</u> resolution !

π^0 calibration is based on this point !!

DVCS Calorimeter



- Description of the Calorimeter
  - Photons Detection
  - Structure of 13 x 16 blocks
  - Blocks = 208 Lead Fluoride (PbF2) cristals of 3 x 3 cm^2 and 18.4 cm of length
  - Cristals → Production of Cerenkov light
  - Resolution on the position (2-3 mm) better than Resolution in Energy (5% / sqrt(E))
- Why is it important to monitor the calibration of the Calorimeter ?
  - To take into account the alteration of cristals blocks due to the high radiation → Data taking with a high Luminosity : $L = 10^{37}\ cm^{-2}.s^{-1}$

2 Methods to calibrate the Calorimeter

1) Elastic Calibration H(e,e'p')

2) π^0 Calibration H(e,e'p'π^0)

Methods based on the « minimization of χ^2 » principle

$$\chi^2 = \sum_{j=1}^{N} \left(E_{\text{theoretical}} - E_{\text{measured}} \right)^2$$

(j = the number of event)

Minimize the difference between the **theoretical** energy and the **measured** energy

$$E_{\text{measured}} = \sum_k C_k \, . \, A_k$$

(k=0,1...or 207)

(C_k calibration coefficients)

(A_k signal amplitude in the calorimeter)

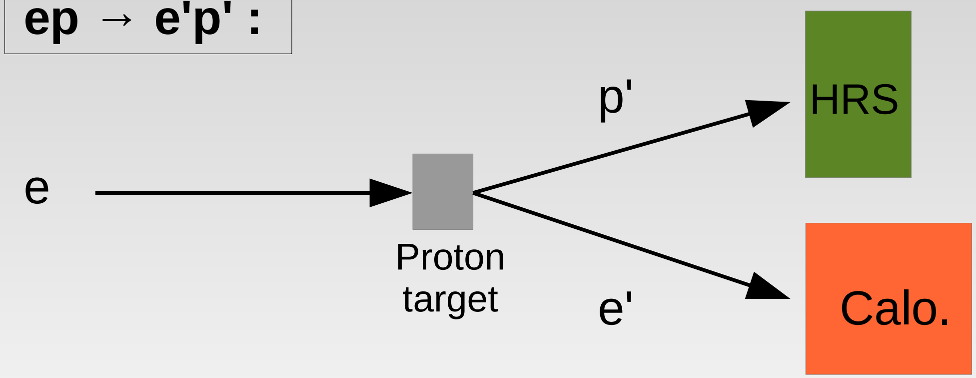
$$\frac{\partial \chi^2}{\partial C_k} = 0$$

(k=0,1...or 207)

The **derivate of χ^2 with respect to C_k equal to zero** allows to find the **208 C_k**

Elastic calibration (I)

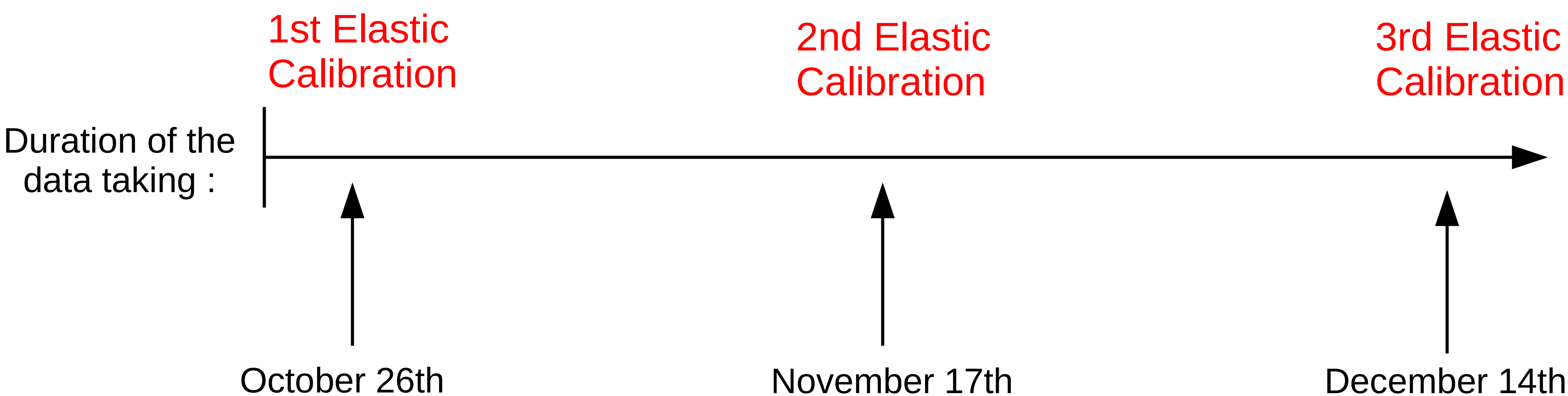
ep → e'p' :



<u>3 Elastic calibrations</u> :

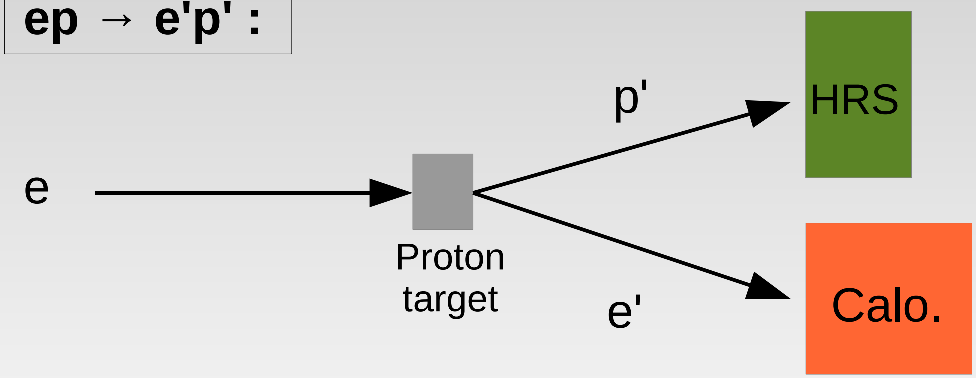
- October 26th 2010
- November 17th 2010
- December 14th 2010

- The **polarity of HRS is reversed** to detect the proton, the **Elastic calibration <u>is not possible</u> during the data taking** !!



Elastic calibration (II)

ep → e'p' :



<u>3 Elastic calibrations</u> :

- October 26th 2010
- November 17th 2010
- December 14th 2010

Minimization of χ^2

(i = the number of blocks in the calorimeter = 208)

$$\chi^2 = \sum_{j=1}^{N}\left(\boxed{E_j} - \sum_{i}\left(\boxed{C_i}\cdot\boxed{A_j^i}\right)\right)^2$$

E_j → So-called « THEORETICAL » Energy

A_j^i → Signal amplitude of the calorimeter block i for an event j

$$E_j = E_b + m - E_j^p$$

E_j: Energy of the scattered electron for an event j

E_b: Beam energy

m: Proton mass

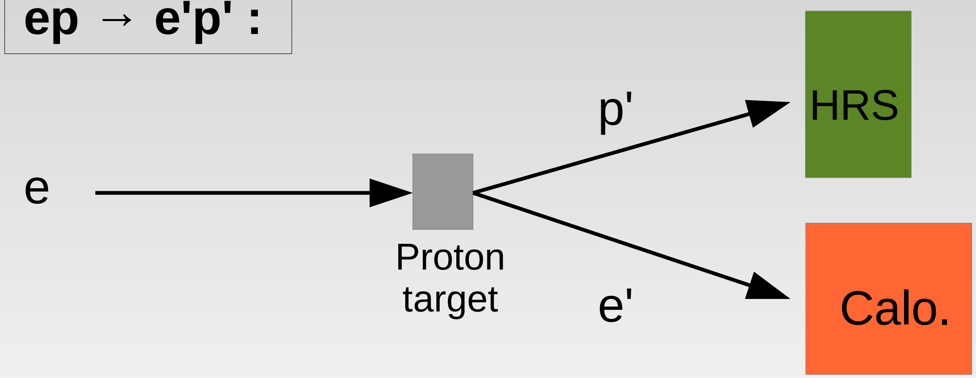
E_j^p: Recoil proton energy

<u>Conservation of energy</u>

Signal Amplitude + Calibration Coefficients → So-called « MEASURED » Energy

Elastic calibration (III)

ep → e'p' :



3 Elastic calibrations :

- October 26th 2010
- November 17th 2010
- December 14th 2010

Minimization of χ^2

$$\chi^2 = \sum_{j=1}^{N} \left(\boxed{E_j} - \sum_i \left(\boxed{C_i} \cdot \boxed{A_j^i}\right)\right)^2 \xrightarrow{\frac{\partial \chi^2}{\partial C_k} = 0} \sum_i \left(\boxed{\sum_{j=1}^{N} (A_j^k A_j^i)} \boxed{C_i} \right) = \sum_{j=1}^{N} (E_j A_j^k)$$

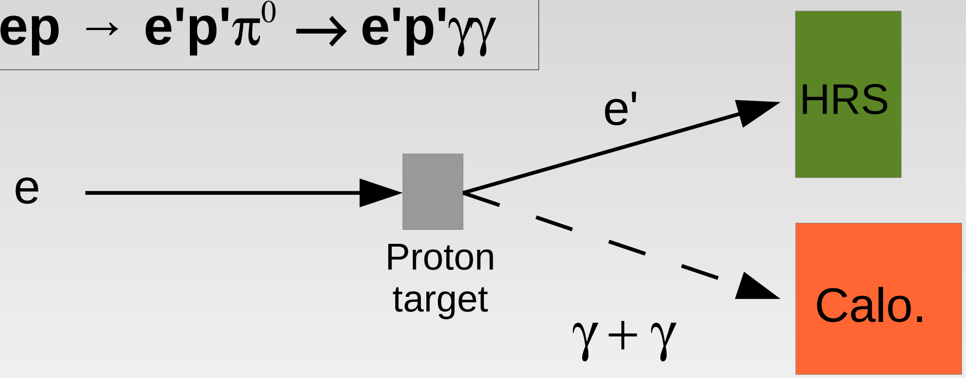
(for any k=0,1...or 207)

We obtain a system of k=208 equations with 208 unknowns C_k

C_k are obtained by inverting the matrix 208X208

π^0 calibration (I)

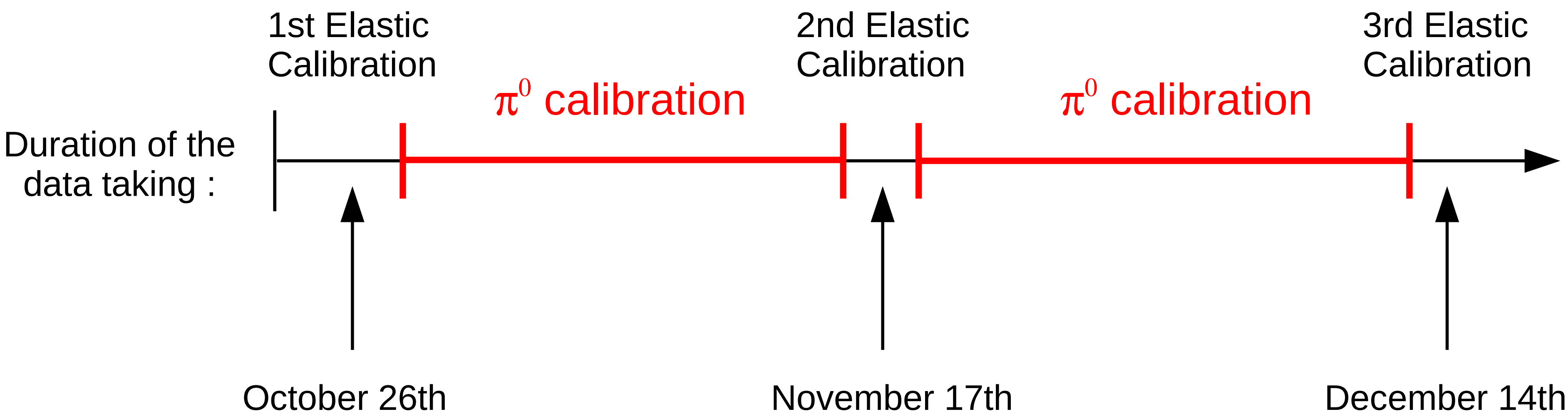
ep → e'p'π^0 → e'p'$\gamma\gamma$



Between the differents Elastic calibrations, the **minimization π^0 method** provides an **optimization** of the calibration

Typically these are two-cluster events !!

- **π^0 calibration <u>is possible</u> during the data taking !!**



π^0 Calibration (II)

$$\chi^2 = \sum_{j=1}^{N} (\boxed{E_j} - \sum_i (C_i \cdot A_j^i))^2$$

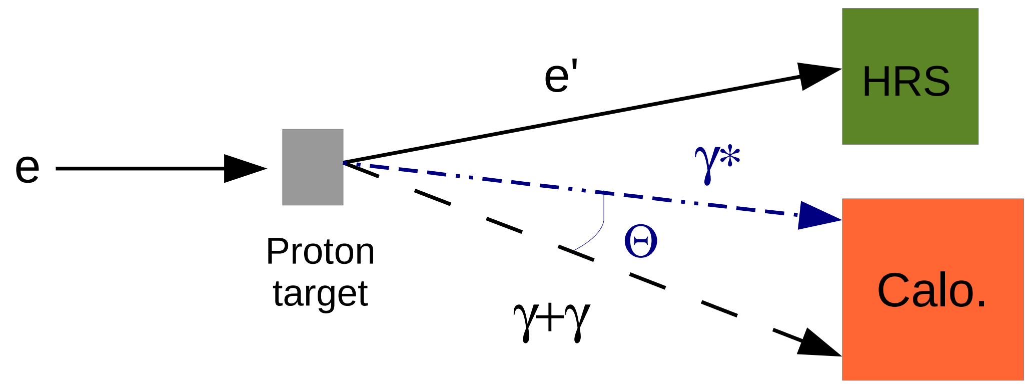
Theoretical pion energy is obtained by :

- **M** : Proton mass = 0.938272 GeV
- **minv** : Theoretical pion mass = 0.1349766 GeV
- **γ*** : virtual photon = (e – e') **(given by the HRS)**
- **Θ** : angle between the pion and the virtual photon (assuming a good resolution in position of the calo.)

$$\cos \Theta = \frac{\vec{q} \cdot \vec{q}_\pi}{\|\vec{q}\| \cdot \|\vec{q}_\pi\|}$$

$\vec{q}$: momentum of the virtual photon

$\vec{q}_\pi$: momentum of the pion



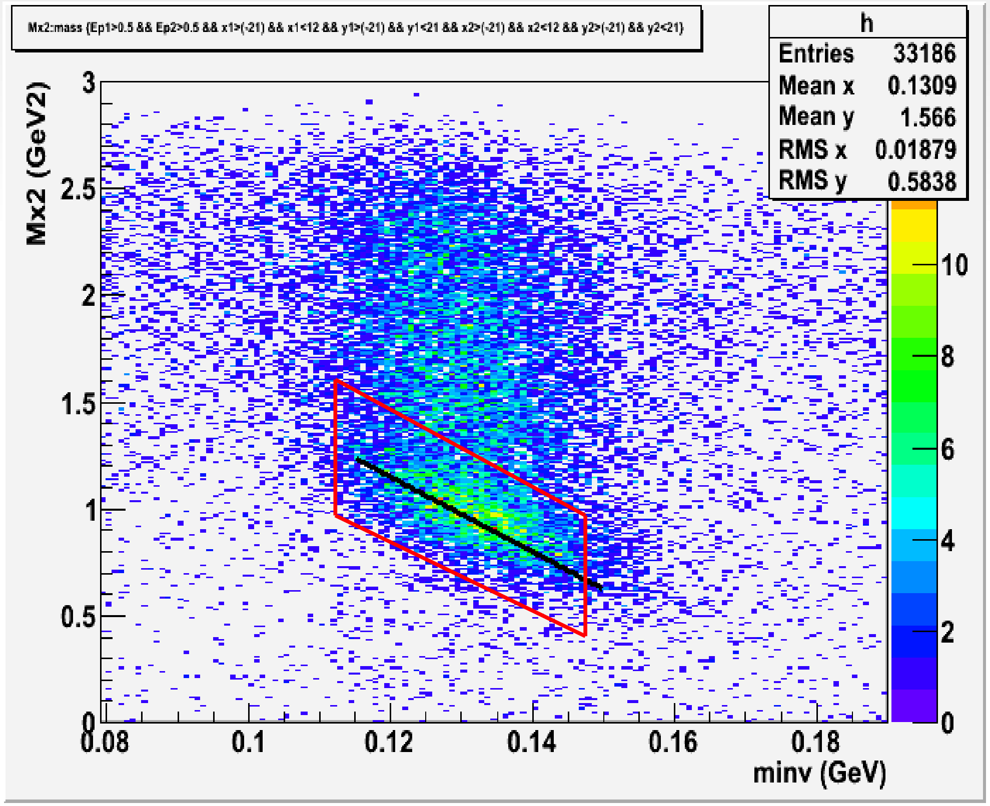
Severals cuts for the π^0 calibration

- Cuts on the HRS :
  - Number of tracks = 1
  - R-function() depends of : theta, phi, dp and vertex
- Cuts on the Calorimeter :
  - Number of clusters = 2
  - Photons energies > 0.5 GeV
- Cut-2D on the minv and the Mx2

$$\mathrm{minv} = \text{Invariant Mass} = \sqrt{(\gamma_1 + \gamma_2)^2}$$

$$M_x^2 = \text{Missing Mass} = M^2(\text{ep -> e } \gamma\gamma(X))$$

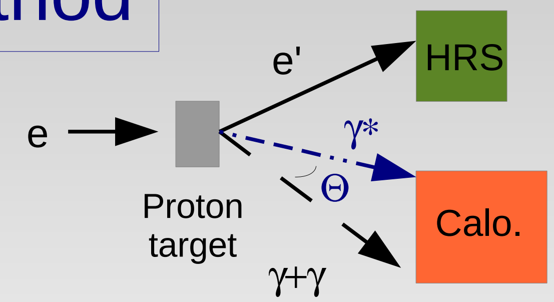
  - 0.5 < Mx2 + 17.5*minv - 2.31 < 1.2



- Cut on the vertex-position (v)

Iterations of the π^0 calibration method

$$E_{block}^{Real} = E_{block}^{Measured} . C^{Elastic} . C_1^{\pi^0} . C_2^{\pi^0} . C_3^{\pi^0} . C_4^{\pi^0} \ldots$$



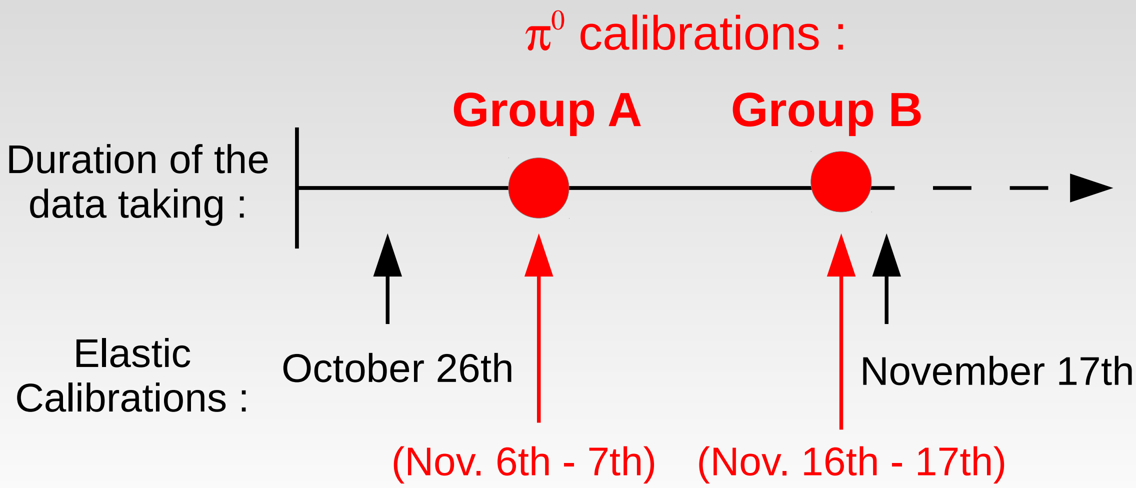
- Θ is determined by the **reconstruction of the Pion position** !
- The **reconstruction in position** depend of the **blocks energies which change at each iteration** !

1st iteration : $E1_{block}^{Real} = E_{block}^{Measured} . C^{Elastic} \longrightarrow \Theta 1 \longrightarrow C_1^{\pi^0}$

2nd iteration : $E2_{block}^{Real} = E_{block}^{Measured} . C^{Elastic} . C_1^{\pi^0} \longrightarrow \Theta 2 \longrightarrow C_2^{\pi^0}$

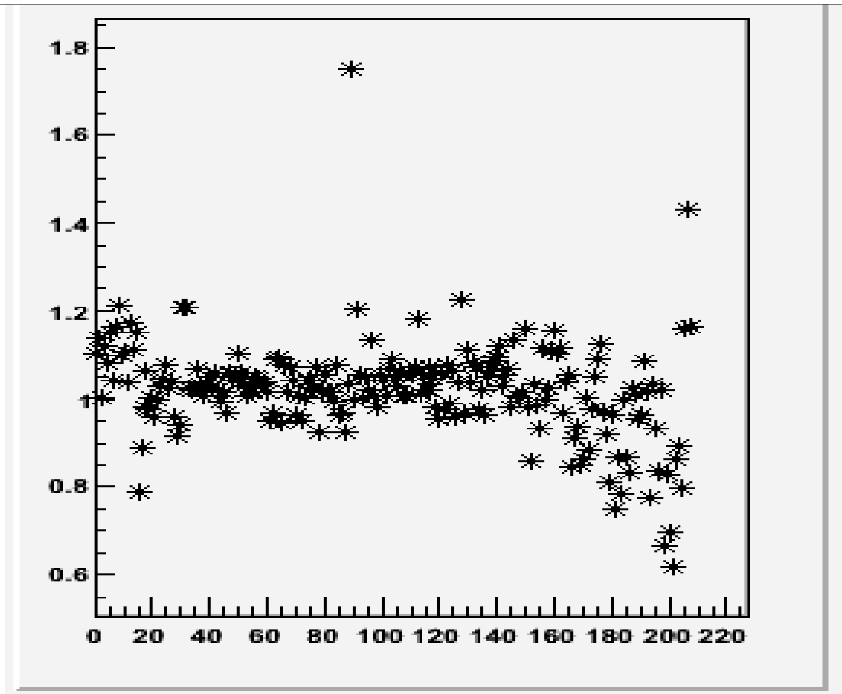
3rd iteration : $E3_{block}^{Real} = E_{block}^{Measured} . C^{Elastic} . C_1^{\pi^0} . C_2^{\pi^0} \longrightarrow \Theta 3 \longrightarrow C_3^{\pi^0}$

Selected Data for the π^0 calibration method



- **We need more statistic than 1 run to calibrate !**
- **With 1 day of data taking (~20 runs) is possible to calibrate**
- **Each kinematic separated in groups of runs of one day each**
- **Studied kinematic** :
  - Beam Energy = 4.82 GeV
  - D2 target

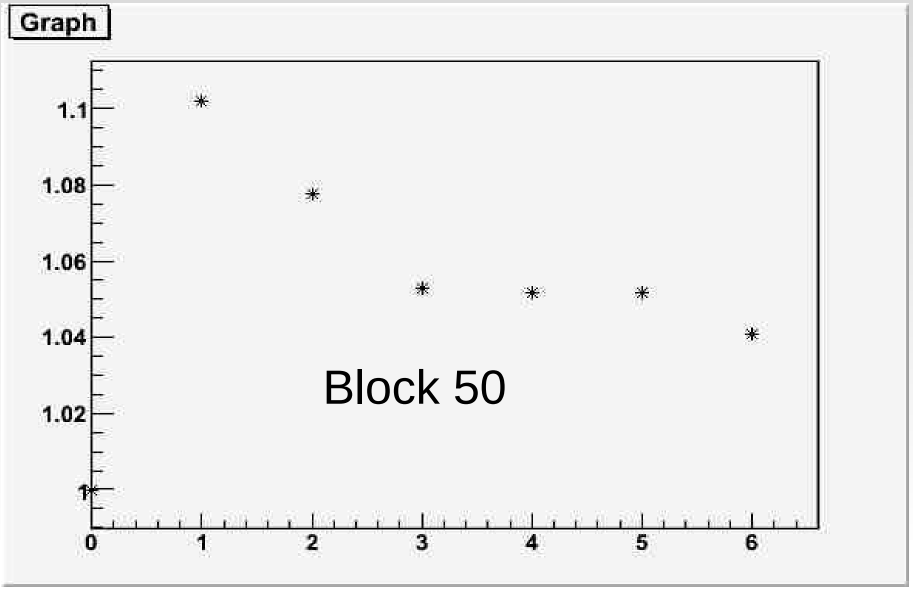
Coefficients as a function of the block number

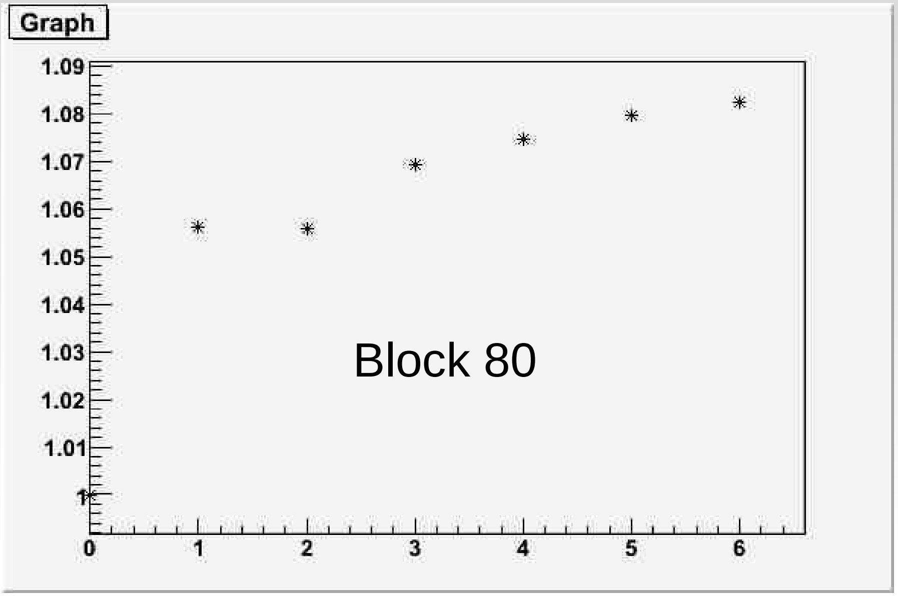


- **2 Studied groups of runs between the two first Elastic Calibrations** :
  - Group A : 23 runs
  - Group B : 23 runs

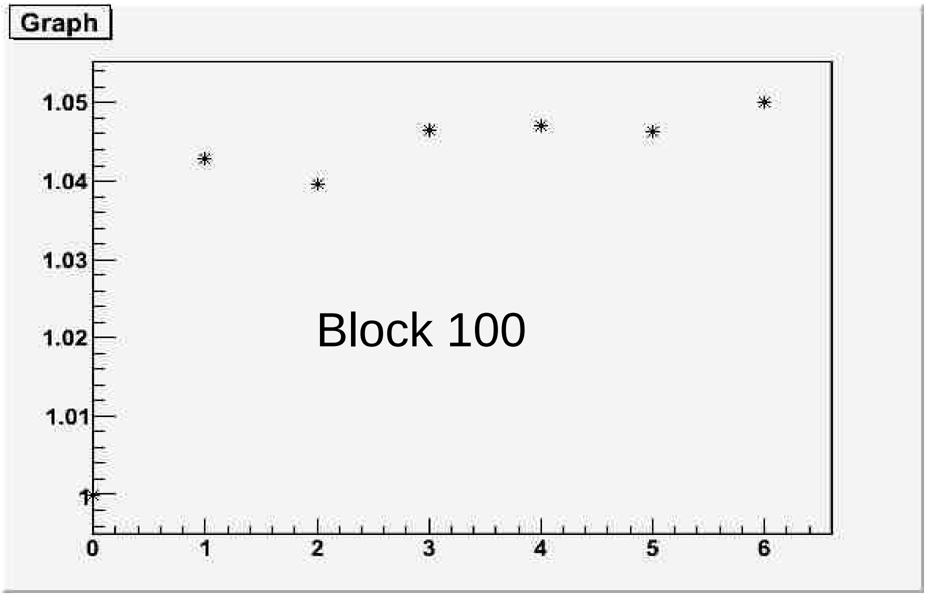
π^0 coefficients of the 1st iteration for the Group A

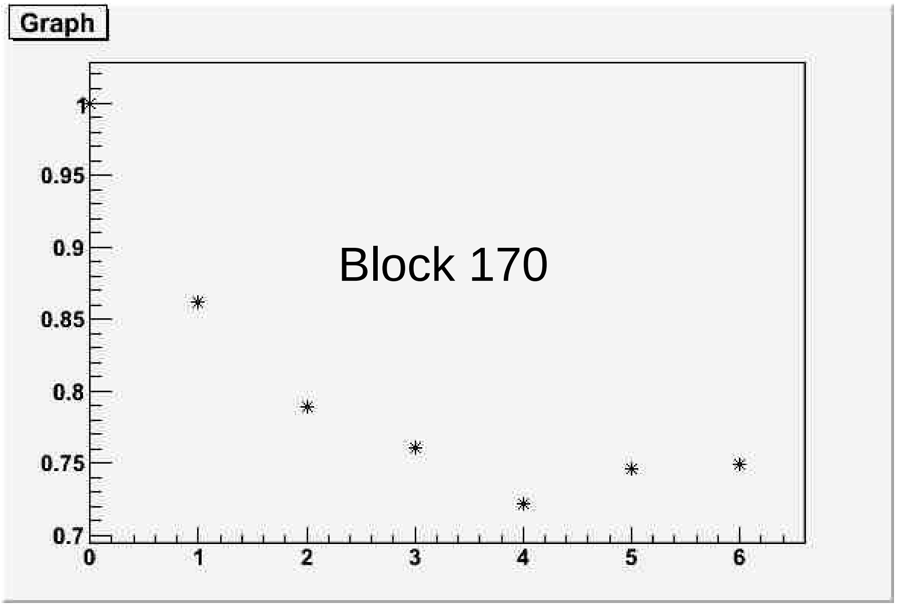
Calibration coefficients as a function of the number of iterations for the group A



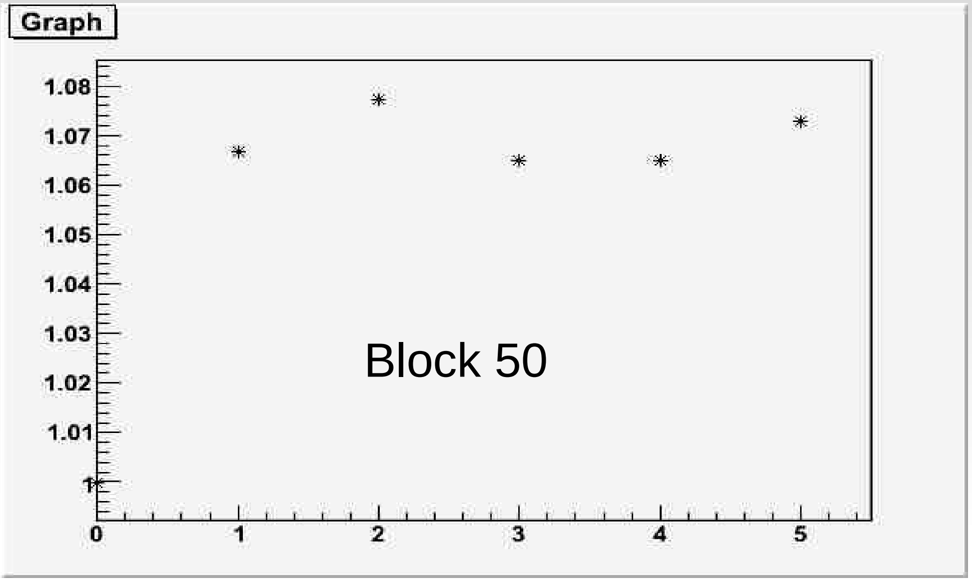


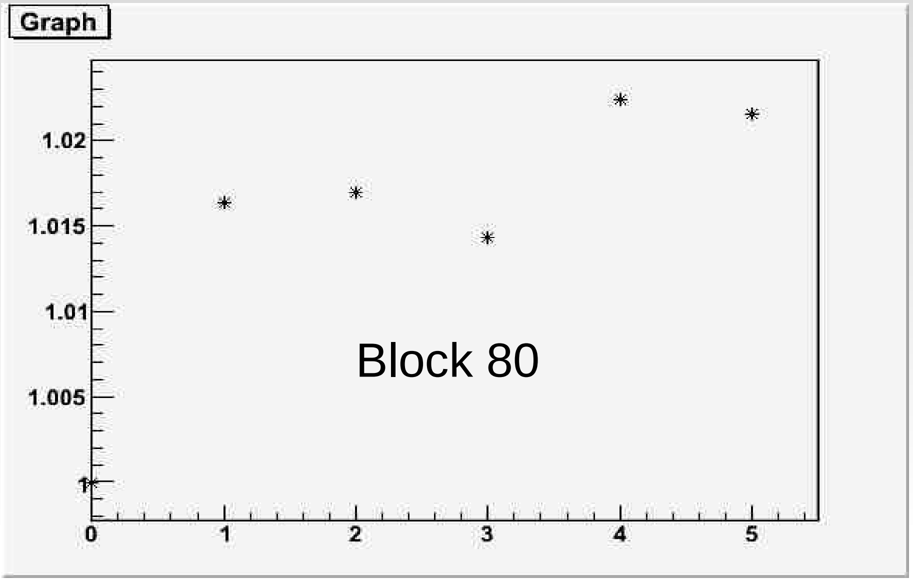
After several iterations, the Coefficients converge !



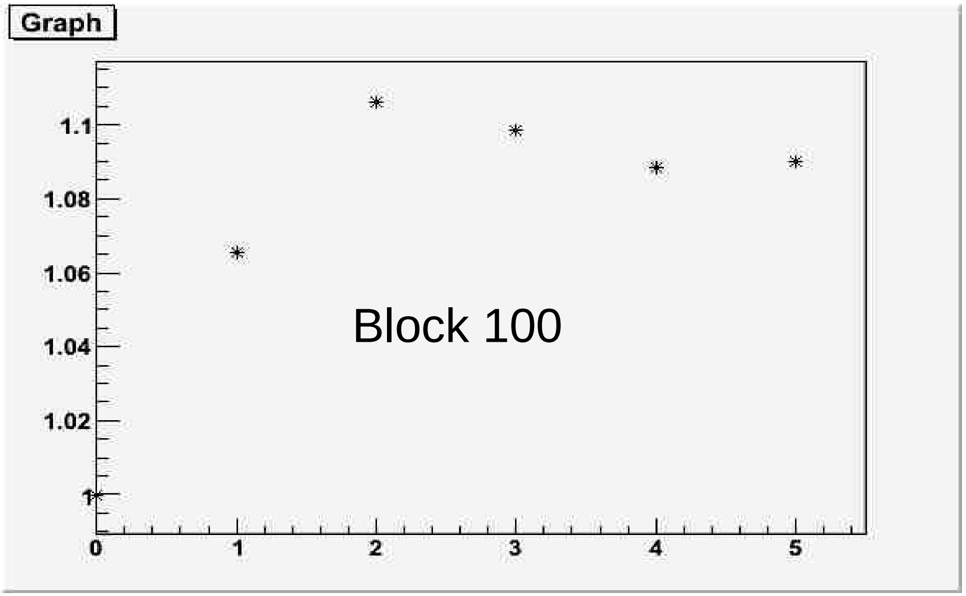


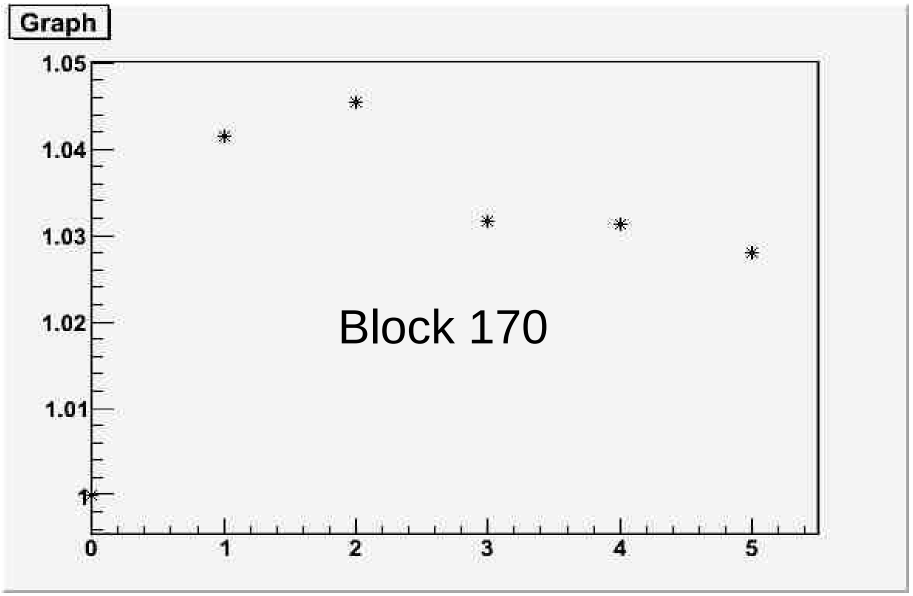
Calibration coefficients as a function of the number of iterations for the group B





After several iterations, the Coefficients converge !

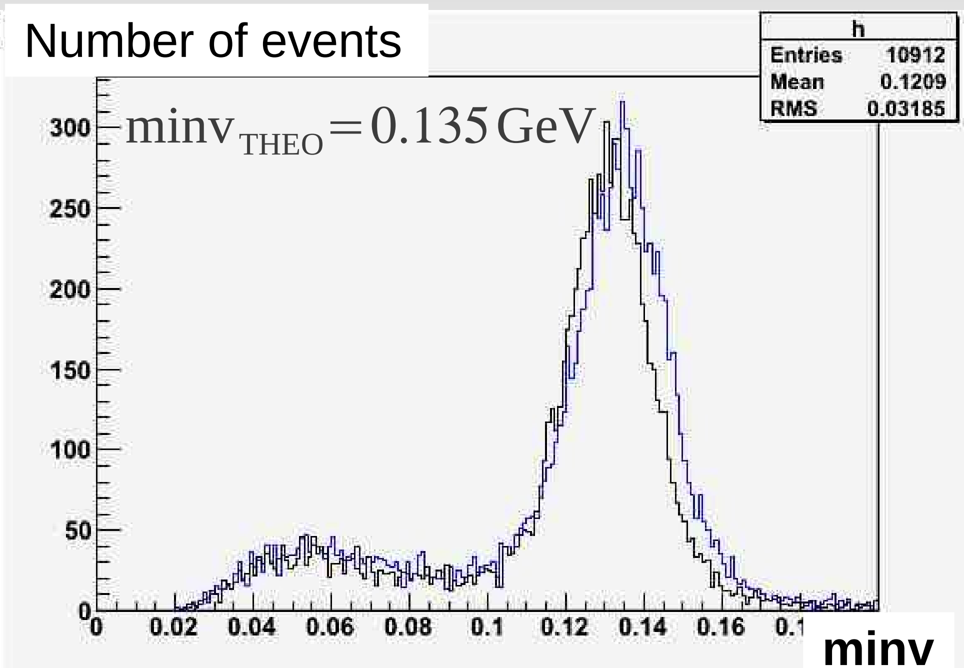


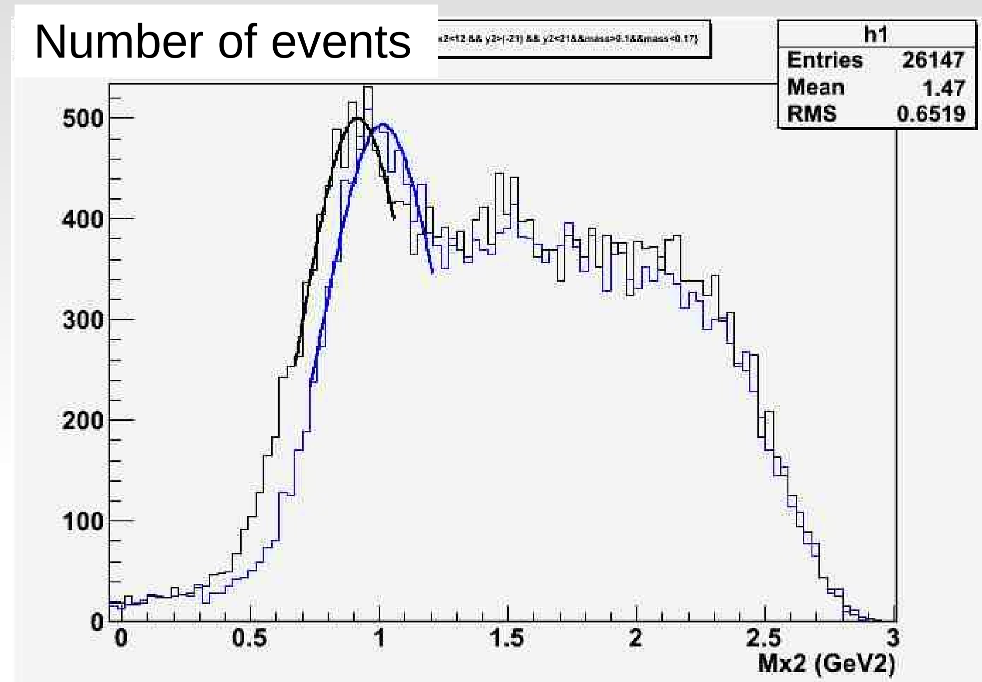


The minv and the Mx2 for the group A

$$\mathrm{minv} = \text{Invariant Mass} = \sqrt{(\gamma_1 + \gamma_2)^2}$$

$$M_x^2 = \text{Missing Mass} = M^2(ep \text{ -> } e\,\gamma\gamma(X))$$





→ Without π^0 coefficients

Fit : mean = 0.131 GeV
Sigma = 10.43 MeV

→ With 5 iterations of π^0 coefficients

Fit : peak = 0.135 GeV
Sigma = 10.93 MeV

→ Without π^0 coefficients

Fit : mean = 1.013 GeV^2
Sigma = 0.23 GeV^2

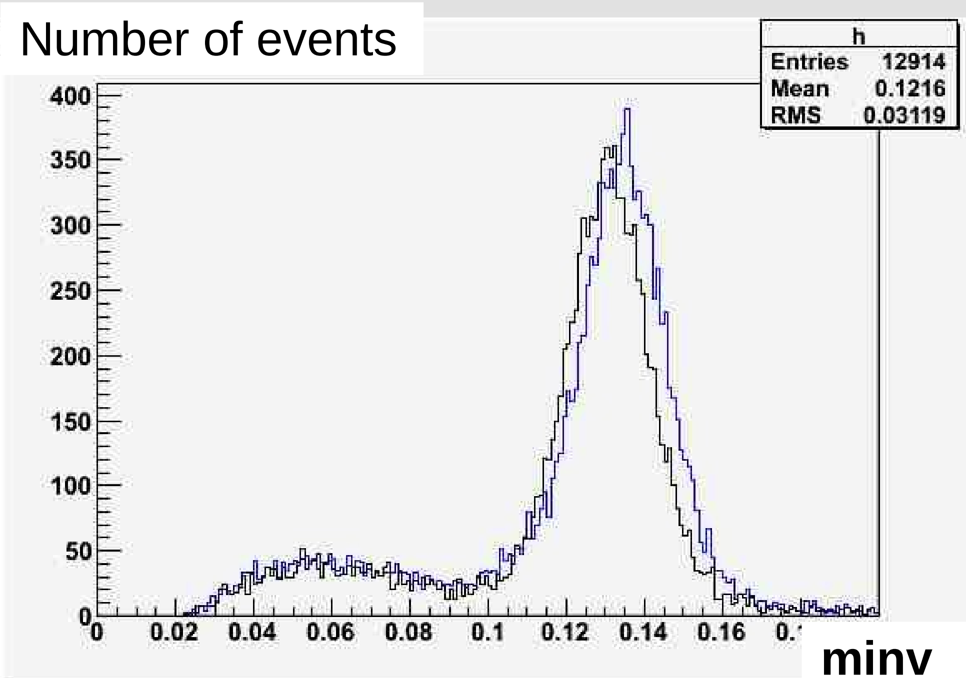
→ With 5 iterations of π^0 coefficients

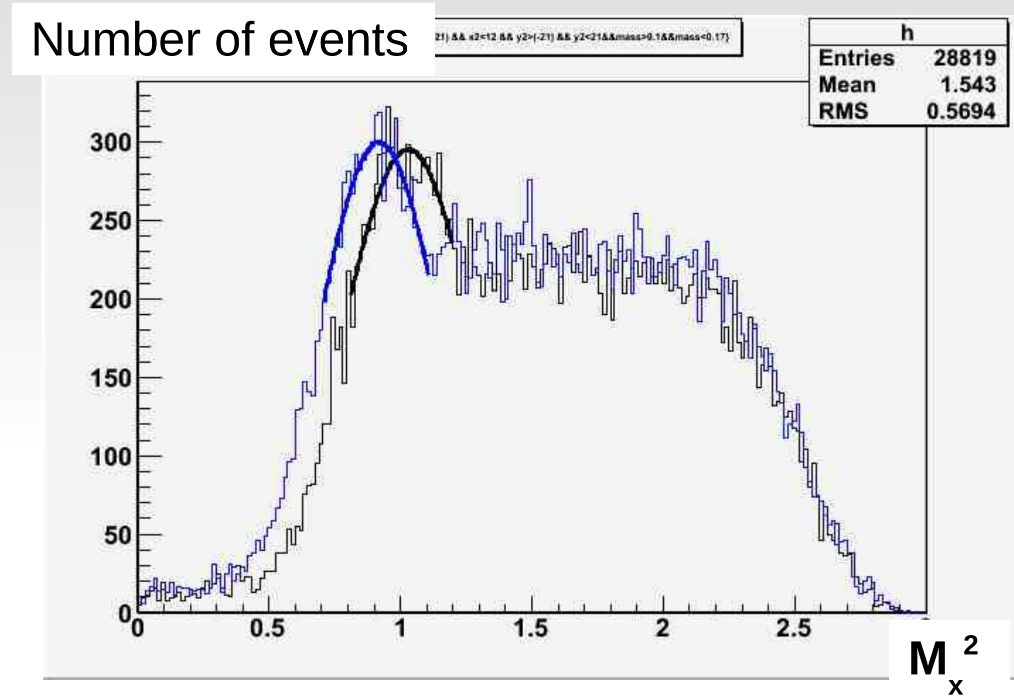
Fit : mean = 0.916 GeV^2
Sigma = 0.21 GeV^2

The minv and the Mx2 for the group B

$$\text{minv} = \text{Invariant Mass} = \sqrt{(\gamma_1 + \gamma_2)^2}$$

$$M_x^2 = \text{Missing Mass} = M^2(\text{ep -> e}\,\gamma\gamma(X))$$





Without π^0 coefficients

Fit : peak = 0.131 GeV
Sigma = 10.01 MeV

With 4 iterations of π^0 coefficients

Fit : peak = 0.135 GeV
Sigma = 10.58 MeV

Without π^0 coefficients

Fit : peak = 1.030 GeV^2
Sigma = 0.25 GeV^2

With 4 iterations of π^0 coefficients

Fit : peak = 0.918 GeV^2
Sigma = 0.23 GeV^2

Conclusion

- **We manage to calibrate the calorimeter with 1 day of data taking**

- **The calibration coefficients converge after 5 or 6 iterations → We will do more iterations to check**

- **The calibration works → After calibration :**
  - minv is closer of the pion mass
  - M_x^2 is closer of the (proton mass)^2

- **We will continue the calibration with :**
  - others days of data taking (= others groups of runs)
  - others kinematics

BACK-UP

π^0 Calibration (III)

$$M_x^2 = M^2 = (q + p_0 - q_1 - q_2)^2$$

The expression of the **Missing Mass** **M_x^2** gives a quadratic equation of Eπ :

$aE\pi^2 + bE\pi + c = 0$

$\Delta = b^2 - 4ac > 0$: 2 solutions for Eπ

$$E_\pi = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

The good one is closer of the measured Eπ value !